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Outcome of reconstruction of cutaneous limb defects in dogs using self-inflating tissue expanders

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Conflict of interest statement

Marc C. Swan FRCS Consultant plastic surgeon – Founding director of Oxtex, with founding shares in the company. Marc was involved only indirectly with cases for advice on placement and case management

Camilla Easter MRCVS – Clinical specialist at Oxtex – full time employee of the company

Guillaume PA Chanoit MRCVS – Veterinary advisor to Oxtex, works as an advisor for small animal cases

1 **Structured summary**

2

3 **Objectives-** To describe the technique of placement and clinical outcome following use of self-
4 inflating tissue expanders (STE) in twelve consecutive cases of reconstruction of distal cutaneous
5 limb defects in dogs.

6 **Methods-** Cases of distal cutaneous limb defect were included. Cases were divided into 3 groups
7 based on location of the placement of the STEs: Group A (4 dogs) : on, or proximal to the elbow
8 and stifle; Group B (4 dogs), distal to the elbow/stifle and proximal to the carpus/ tarsus ; Group
9 C (4 dogs) distal to the carpus and tarsus. Owner's satisfaction and clinical outcome were
10 documented.

11 **Results-** Thirteen cases were originally included but one was excluded because of incomplete
12 follow-up. One case experienced premature removal of the STEs before expansion started. A
13 mean of 5 STEs were implanted per dog (range 2-9). Devices were explanted after a mean of 24
14 days (range 13-42 days). Primary closure was achieved in 8/11 cases including all cases from
15 Group A, and 75% and 33% of cases from Group B and C respectively. All incompletely
16 reconstructed defects or cases of wound dehiscence healed by second intention. Eight out of 12
17 owners were satisfied.

18 **Impact of the work** - Skin expansion using STE can be used as an alternative for the
19 reconstruction of limb defects in dogs where direct primary closure would otherwise not be
20 achievable. Defects below the carpus and tarsus are more challenging to treat with STEs.

21

22 **Key words**

23 Soft Tissue Surgery, Reconstructive surgery, Skin expansion

24

25 **Introduction**

26 Tissue expansion was first described for soft tissue in the mid 20th century (Neumann, 1957). It
27 is now an established reconstructive technique in human surgery (Swan, 2007) and has a host of
28 potential applications in veterinary surgery (Pavletic, 2010), in particular in the field of
29 reconstructing limb cutaneous defects.

30 Tissue expansion works by inducing ‘biological creep’ (generation of new tissue secondary to a
31 chronic stretching forces) to the skin as opposed to producing tissue elongation beyond inherent
32 extensibility, which is defined as “mechanical creep”. Mechanical creep induces a straightening
33 of the convoluted collagen fibres, microfragmentation of the elastic fibres and movement of
34 water from the collagen network. Conversely, the new tissue generated by “biological creep”
35 (similar to events such as pregnancy, skin growth over tumours or obesity) undergoes completely
36 different molecular and cellular changes with epidermal thickening and angiogenesis (Wilhelmi
37 et al., 1998).

38 Soft tissue expansion in the limbs of dogs has the advantage of additional skin for use in
39 reconstructive procedures where there is otherwise limited local tissue available for the rotation
40 or advancement of a skin flap (Swaim, 1980). It is widely regarded that large skin defects of the
41 limb, especially the distal limb are often difficult to manage (Spodnick et al., 1993); treatment
42 often requires prolonged open wound care, second intention healing (Bright RM, 1985, Prpich et
43 al., 2014) and/or the use of free skin grafts (Riggs et al., 2015).

44 Since its inception, tissue expansion has been achieved by inflating a silicone balloon placed
45 subcutaneously, using saline to fill the balloon through a subcutaneous (or occasionally an
46 external) port. The technique was first reported in veterinary medicine in 1989, in three horses,
47 one heifer and one dog (Madison et al., 1989). Subsequently the technique was refined more
48 specifically to expand distal extremities in dogs (mid crus and mid ante brachium) in both
49 experimental (Keller et al., 1994) and clinical settings (Spodnick et al., 1993, Keller et al., 1994).

50 It was noted that even if the expanders were well tolerated with few complications, mild
51 discomfort following percutaneous injections to fill the balloon was reported (Keller et al., 1994).
52 Moreover the physical bulk of traditional balloon-type expanders often precluded their use in
53 discrete anatomical locations (Swan et al., 2012). Furthermore the need for weekly expansion
54 through a buried port can be painful and time consuming, may lead to an increased rate of port
55 site infection with potentially greatly increased cost to the owner. These limitations have led to
56 the development of self-inflating tissue expanders.

57 A self-inflating tissue expander is an osmotic expander formed of a hydrogel core (inert
58 hygroscopic polymer) and external silicone coating. Once implanted, water is drawn by osmosis
59 from the surrounding tissues into the device, which can spontaneously expand. The rate and
60 extent of expansion is controlled by the external Silicone coating (Chummun et al., 2010). A self-
61 inflating tissue expander has many advantages over the traditional balloon devices. The absence
62 of a filling port and the ability of the hydrogel to conform to almost any configuration (Swan et
63 al., 2011) enables this novel type of tissue expander to be used in anatomical locations that would
64 otherwise be very difficult to utilise traditional expansion techniques using balloon devices. The
65 indications for self-inflating tissue expander in skin reconstruction from the human literature
66 include: the expansion of a flap to resurface an adjacent defect; the expansion of tissue prior to
67 placement of an implant; and the pre-expansion of a flap or graft donor site (Sharpe, 1992).

68 Among others they have been used for breast reconstruction, cleft palate repair, scar and burn
69 resection (Ronert et al., 2004, Chummun et al., 2010, Lohana et al., 2012, Berge et al., 2001).

70 The use of self-inflating tissue expanders has never before been reported in veterinary clinical
71 species. The purpose of this prospective study is therefore to report the technique of placement
72 and clinical outcome in dogs with limb defects that were managed using self-inflating tissue
73 expanders across North America, UK and Europe. This case series reports the use of a novel

74 self-inflating anisotropic hydrogel tissue expander, which consists of a hydrogel core coated in
75 medical grade silicone, manufactured to ISO 13485 standards for prospective human usage.

76

77

78 **Materials and Methods**

79 The study received ethical approval from the Institutional Ethical Review Committee of
80 XXXXX.

81 Cases managed with the a self-inflating tissue expander (STE) (Expaniderm, Oxtex Ltd , Oxford
82 UK) (Figure 1) were prospectively included and signalment, clinical history, reason for expander
83 use, surgical technique, owner satisfaction, expander ease of use and clinical outcome including
84 complications were recorded.

85 The device expands in three phases: a delay phase for 3-4 days after implantation when no
86 expansion occurs to enable initial wound healing, then a controlled phase of linear expansion,
87 followed by a plateau phase (reached within 2-4 weeks) when the device is fully expanded and
88 will remain so until removed for the second-stage reconstruction.

89 Dogs were included if they presented with a skin defect on a limb that could not be closed
90 without a skin graft, flap or tissue expansion. The presence of active infection (evidenced by
91 culture results and/or visual inspection) was a contra-indication. In the case of tumour resection,
92 the preliminary cytology or histopathology results was first confirmed. All therapeutic options
93 were presented to owners; some guidance was offered but the decision to proceed with skin
94 expansion was based on the owners' decision. Informed consent form was obtained from the
95 owners. Cases were excluded if follow-up was not available or if the information with regards to
96 tumour grading and / or staging was insufficient.

97 Cases were divided into 3 groups based on anatomical positioning of the expanders. Group A (4
98 dogs) comprised of cases where the expanders were placed on, or proximal to, the elbow and

99 stifle in the forelimb and hindlimb respectively. Group B (4 dogs) comprised of cases where
100 expanders were placed distal to the elbow and proximal to the carpus in the forelimb and distal to
101 the stifle but proximal to the tarsus in the hindlimb. Group C (4 dogs) comprised cases where
102 expanders were placed distal to the carpus and tarsus.

103 Indications for placing the expanders were as follows: prior to neoplastic tumour resection (n=5),
104 prior to non-neoplastic tumour resection (n=3) and to aid primary wound closure of non-healing
105 wounds (n=4). Table 1 documents case descriptions and indications for expansion for all cases
106 included in the study.

107 Owner satisfaction was obtained by the veterinary surgeon performing the surgery once the
108 wound had fully healed and was graded as either satisfied or not satisfied.

109 Expander ease of use, as assessed by the veterinary surgeon, was graded as good (expanders
110 implanted as planned including location and number of devices), fair (expanders not implanted as
111 planned either location and numbers but leading to satisfactory / complete reconstruction) or poor
112 (expanders not implanted as planned leading to partial reconstruction).

113 Clinical outcome was defined according to the quality of wound closure and complications.

114 Outcome was categorised into four groups:

115 *Excellent*: no complications during implantation or skin expansion and full reconstruction
116 *Good*: minor complications during implantation or expansion - full or partial
117 reconstruction needing no further surgery post reconstruction
118 *Fair*: major complications during implantation or expansion - full or partial reconstruction
119 – no further surgical intervention required post reconstruction
120 *Poor*: major complications during implantation or expansion requiring further care under
121 sedation or anesthesia - partial or no reconstruction

122 All dogs had two general anesthetics, one for the initial implantation and a second for the
123 subsequent explantation and wound reconstruction. Analgesia was provided with a combination

124 of opioids and non-steroidal anti-inflammatory drugs (NSAID) as appropriate. All dogs were
125 induced, following premedication, using intravenous anaesthetic agents and maintained on
126 Isoflurane or Sevoflurane. Prophylactic antimicrobials (including amoxicillin-clavulanic acid,
127 second generation cephalosporin or metronidazole) were administered perioperatively to all dogs.
128 Metronidazole was administered in only one dog based on culture and susceptibility testing. Dogs
129 with open wounds were treated with antimicrobials based on culture and sensitivity testing
130 wherever possible (2 cases). Postoperative infections were treated with antibiotics based on
131 culture and sensitivity when possible. The use of bandages and wound drains was according to
132 the veterinary surgeon's preference.

133

134 *Implantation technique*-The implantation technique followed a series of specific guidelines: (1)
135 The incision for device insertion was made away from the proposed position of the device to
136 minimise the risk of wound dehiscence during expansion; (2) The incision was made in normal
137 skin, avoiding scar tissue, ulcerated or highly irradiated skin; (3) Care was taken so that the
138 incision did not compromise the vascularity of the subsequent skin flap (Swan, 2007) and
139 whenever possible the incision was made such that it preserved the proximal blood supply; (4) In
140 oncological cases, the incision was made beyond the planned margins for tumour removal; (5)
141 Blunt dissection was used to create a sub-cutaneous pocket and the pocket was made sufficiently
142 large to accommodate the STEs. This was checked using a trial device of the same size as the
143 STE before final implantation; (6) When inserting the STEs, care is taken not to damage the
144 silicone membrane coating the expander (such as the use of toothed forceps is avoided); (7)
145 Dead space was closed to prevent migration of the STEs; and (8) meticulous haemostasis is
146 performed to reduce the risk of haematoma formation. Incisions were closed in a routine fashion
147 (Figure 2 and 3).

Two expander types were used. They were both cylindrical with a diameter of 27mm. One expander device had a height of 5mm height and expanded to 18mm, whereas the alternative device had an initial height of 9mm and expanded to 25mm (Figure 1).

Explantation technique-Devices were removed through the incision created at the leading edge of the skin flap whenever possible, however this was dependent on anatomical location. When the presence of an expander created a fibrous capsule, scoring or excision of the capsule allowed the elasticity of the overlying skin flap to be restored. During scoring care was taken not to compromise the vascularity of the skin flap. Following explantation, the skin defect was reconstructed fully or partially using the expanded skin either to aid direct primary closure or as an advancement flap.

Results

Thirteen consecutive cases of dogs with skin defects on the limb, managed with self-inflating tissue expanders between July 2014 and March 2016 were assessed. All cases were operated on by different veterinary surgeons in a number of institutions. One case was excluded from the present report due to loss of follow-up. For one further case, we could not report the outcome on reconstruction, expansion and wound closure following STE placement as the STEs had to be removed within 24 hours post placement (i.e. before any inflation had occurred). Therefore, outcome of implantation technique, rate and type of complications and procedure grading are reported on 12 cases whereas outcome of expansion, type of reconstruction techniques used, and wound closure are only reported on 11 cases.

172 *Implantation and Expansion-* A mean of 5 STEs were implanted per dog (range 2-9). Devices
173 were explanted after a mean of 24 days (range 13-42 days). In 6 cases the STEs expanded as
174 intended without complication. In 2 cases, both in Group C, major complications were seen
175 during expansion: in one dog the STEs extruded through the skin and in the other case the
176 devices were removed early due to skin necrosis overlying the devices. In another dog in group
177 C, the devices were removed 24 hours post implantation (before expansion had started). In this
178 case the un-expanded devices were placed on the palmar aspect of the carpal region and appeared
179 to compromise blood supply to the distal forelimb, as evidenced by the profound change in
180 colour of the leg distal to the STE placement site. Once the expanders were removed the leg
181 returned to a completely normal colour. One STE in group A ruptured by explantation although
182 there was no macroscopic damage to the skin and full expansion of the skin was achieved.
183 Rupture was thought to be due to incorrect STE handling at implantation. In 3 cases minor
184 complications occurred during expansion: 2 of these were incisional infections (suspected based
185 on visual inspection) of which both dogs were being treated for an open wound. In 1 dog from
186 group C there was minor tissue necrosis overlying one of the expanders, which did not affect the
187 clinical outcome. 6 dogs were bandaged throughout expansion.

188

189 *Reconstruction-*All dogs underwent a second general anaesthetic for reconstruction. STEs were
190 removed and in cases with a mass to be resected this was undertaken during the same anaesthetic
191 episode. In 6 cases the expanded skin was used as an advancement flap and in 5 cases the
192 expanded skin was used to aid direct primary closure.

193

194 *Wound Closure-* This was assessed in 11 of the 12 cases. Primary closure was achieved in 8/11
195 (73%) cases. In group A, all 4 cases achieved primary closure (100%). In group B 3 of the 4
196 (75%) cases achieved primary closure. In Group C 1 of the 3 (33%) cases achieved primary

closure. Two of the cases from group A that had initial primary closure, subsequently encountered complications. One case resulted in complete wound dehiscence due to improper device positioning leading to excessive tension in the area of the defect where no tissue expander had been placed. In the second case there was partial ischemia of the advancement flap caused by inappropriate location of the implantation incision, which disrupted a significant portion of the blood supply to the advancement flap, resulting in nearly 90% of the skin appearing non-viable. In 3 cases (1 from group B and 2 from group C) primary closure was not achieved; however in all cases the resultant defect required to heal by second intention was greatly reduced due to the additional skin.

Two of the three cases of group C failed to achieved primary closure due to tissue necrosis during expansion. In one case the STEs were removed prior to full expansion due to necrosis of the overlying tissue, this meant that there was insufficient skin generated for primary closure, however the skin that was expanded was viable and used to reduce the size of the defect. In the second case in group C the STEs extruded prior to explantation, however extra skin was still generated and this was used to aid primary closure of the original defect and only a small open wound was left at the donor site which healed, without complication, via secondary intention. In the one case from group B where primary closure was not achieved this was due to placement of the expanders. Rather than being placed laterally and medially around the wound to be reconstructed, half the devices were placed proximally, which significantly reduced the ability to clinically use the skin that had expanded.

217

Complications-Table 2 outlines all complications and procedure scoring outcomes. One of the 12 cases required additional surgery to remove the implants within 24 hrs after initial placement, as it was perceived that the implants were disrupting the blood supply to the leg. The 3 incompletely reconstructed defects and the 4 cases where dehiscence occurred all healed by second intention

222 without the need for further surgical intervention. Two dogs developed incisional infections,
223 both of which were successfully treated with antibiotics (amoxicillin and clavulanic acid). The
224 infections did not affect expansion of the STEs, reconstruction or clinical outcome.
225 Two dogs, both from group C, developed major complications during expansion. One had STEs
226 removed early and reconstruction carried out with partially expanded skin. This resulted in a
227 successful partial reconstruction that went on to heal without complication via secondary
228 intention. The second case experienced device extrusion, however there was still expanded skin
229 that was used to aid the reconstruction. The original defect was closed using the expanded skin
230 and a small secondary donor defect was left to heal via second intention. This went on to heal
231 without complication.

232

233 *Procedure grading* -On procedure grading 6/12 cases were scored as either excellent or good,
234 5/12 being scored as fair and 1/12 scored as poor. There were no complications seen at
235 implantation and all surgeons scored the ease of use of the device as either good (7/12) or fair
236 (5/12). Owners were asked to score their experience as being either satisfied or not satisfied,
237 8/12 owners reported that they were satisfied whereas 4/12 reported that they were not satisfied.

238

239 **Discussion**

240 This study is the first to present a range of indications, outcomes and complications associated
241 with the use of self-inflating tissue expanders in a limited number of dogs. This type of tissue
242 expander has never previously been used in veterinary clinical practice and this paper
243 demonstrates an accurate and open documentation of the first 11 consecutive patients throughout
244 Europe and North America. As a prospective study it shows the initial learning curve of this
245 product.

246 Due to the ease of use this product and its application in limb reconstruction, the majority of
247 cases are seen and dealt with in first opinion practices. This is reflected by the fact that 11
248 different surgeons took part in this trial. There was extensive support given by both a board
249 certified veterinary surgeon and a human consultant reconstructive plastic surgeon, highly
250 experienced in tissue expansion. Therefore this product was trialed in a realistic setting for its
251 intended use.

252 Of the 3 anatomical groups, group C had the least favorable outcomes and was the only group to
253 have major complications. The reason for complications distal to the carpus and tarsus is not
254 fully understood but one hypothesis is that the pressure of the tissue expander device on the
255 overlying skin exceeds the tissue perfusion pressure in this location thus leading to local tissue
256 ischaemia and subsequent skin necrosis. There was no evidence of skin necrosis when the
257 devices were placed proximal to the carpus or tarsus (groups A and B). Therefore it would be
258 recommended that current self-inflating expanders only be placed distal to carpus or tarsus under
259 careful consideration. It is possible that a device that expands more gradually would potentially
260 overcome the problem of tissue necrosis.

261 Of the 8 cases with devices placed proximal to the tarsus and carpus, 6 had no complications
262 throughout expansion and 2 cases had minor complications, thus demonstrating that use of these
263 devices in this region is safe and effective. The minor complications were incisional infections
264 which both resolved completely with antibiotic treatment. None of the minor complications
265 during expansion affected outcome.

266 Precise and correct anatomical placement of the device is crucial to the quality and quantity of
267 the expanded skin required for reconstruction (Hudson and Grob, 2005). It is advised that an
268 expander is placed a minimum distance from the defect and that the expander is 2.5-3.0 times the
269 size of the defect to be reconstructed in order to succeed in primary closure (van Rappard et al.,

1988). This assumption is based on studies performed on human skin, however studies carried out by Bartell and Mustoe found that there was no statistical difference between human and dog skin when tested for elastic and biomechanical properties and has been established as the best animal for tissue expansion (Bartell and Mustoe, 1989). It is therefore not known whether the same principles should apply to canine skin expansion. However, incorrect placement was seen in 2 cases in which less than excellent outcomes were achieved. In one case, rather than the devices being placed along the lateral and medial edges of the defect to be reconstructed 5 of the 8 devices were placed proximal and medial. This meant that although the devices expanded as expected the extra skin created was difficult to utilize distally. As previously stated in one case the incision for placing the STEs cut across the blood supply to the subsequent advancement flap, thereby resulting in its partial necrosis.

The expanders tested in this study are anisotropic (only expanding in one vertical direction), therefore the additional skin gained is through the increase in height of the device. Thus the most efficient way to site the STE's, in order to achieve the maximal amount of expanded skin is in a longitudinal configuration of STE's along the length of the defect, or, where possible, one row either side of the defect.

Complications arising from tissue expansion are relatively common, but the majority are of a minor nature (Malata *et al.*, 1995). In two retrospective studies by Casanova *et al.* (2001) and Pandya *et al.* (2001), the overall complication rates in lower limb tissue expansion in humans was cited as being 19.4% and 43% respectively, of which major complications were seen in 15.5% and 17% accordingly (Casanova *et al.*, 2001) (Pandya *et al.*, 2002).

In this study the only group in which major complications were seen during expansion was those where the STEs were implanted distally to the carpus / tarsus. It is hypothesized that due to the

294 distal location of the STEs the pressure exerted by the STEs exceeded the local tissue perfusion
295 pressure thus resulting in tissue ischemia and subsequent tissue necrosis. This is similar to the
296 human literature, which reports that complications of the extremities are generally higher than
297 those of the trunk and scalp (Hallock, 1987). The reason why one case developed a suspected
298 distal limb ischemia following STE placement is unknown. This dog was the only one for whom
299 the STEs were placed on the palmar aspect of the carpal region so it could be hypothesized that
300 the STE were interrupting the blood supply to the distal leg from the median artery, the reason
301 why the dorsal blood supply from the cranial superficial antebrachial artery did not suffice is
302 unknown. Following this complication, we are now recommending that STEs are not placed in
303 the palmar region of the carpus.

304

305 In cases of tumour resection, reconstruction was carried out before the margins were known. It is
306 therefore possible that this method of reconstruction could be associated with cancer cells
307 seeding, although we did not encounter this complication in our study. This issue might be more
308 prevalent with tumours such as mast cell tumours and high grade STS , which typically require
309 larger resection margins (Ryan et al., 2012). The very low occurrence of these tumours in our
310 study population (no high grade STS and only one mast cell tumour) can explain why we did not
311 encounter local recurrence due to cancer cells seeding. We however believe that cancer cell
312 seeding is a potentially serious issue to consider whilst using STE and, would advise against
313 using those in the management of feline fibrosarcoma for this reason. An alternative would be to
314 resect the tumour at the time of STE placement. This was not advised as we estimated that the
315 management of an open wound in addition to the management of the STE sites could potentially
316 increase the risk of complications, including infection. We also felt that the presence of an open
317 wound could act as a “path of least resistance” and could increase the risk of premature STE
318 dislodgment through the open wound, considering that STE were always placed on the edge of

319 the proposed resection site. Ultimately the decision to not resect the tumour at the time of STE
320 placement was based on subjective more than objective considerations.

321

322 Traditional tissue expansion is performed over several weeks to months. It was found that when
323 skin was expanded proximal to the carpus and tarsus there were no detrimental effects of rapid
324 two week expansion, compared with dogs where the device was expanded more gradually over
325 four weeks (Keller et al., 1994). This is supported by Mustoe *et al.* who concluded that rapid
326 tissue expansion (two weeks in dogs) did not demonstrate any deleterious effects when compared
327 with a more conventional regimen (Mustoe *et al.*, 1987). This was confirmed in the present study.
328 Mean expansion time in this study was 24 days. We started the study aiming for 28 days however
329 it became apparent that there was little to be gained from leaving the expanders longer than 14
330 days, which is our current expansion time recommendation.

331 Even if the small number of included cases precludes drawing definitive conclusions, it does not
332 presently appear that the incidence of complications is correlated with an increase number of STE
333 placed. In fact, in two of the cases where the STEs were placed adjacent to open non-healing
334 wounds, both wounds spontaneously started to contract. It is hypothesised that was due to two
335 reasons. Firstly, the dissection of a subcutaneous pocket causes a delay phenomenon, which
336 increases the rate of wound healing due to dilation of existing vessels (Taylor *et al.*, 1992);
337 secondly the mechanical stress placed on the skin by the expanding STE may result in an
338 increase in local angiogenesis. In a prospective soft tissue reconstruction study in humans using
339 traditional balloon expanders, increased expression of vascular endothelial growth factors
340 (VEGF), a major angiogenic cytokine, was demonstrated compared to non-expanded control
341 patients (Lantieri *et al.*, 1998).

342

343 In dogs, several options can be used for reconstruction on the limb including allowing a wound to
344 heal via second intention (with or without the adjunct of negative wound pressure therapy),
345 surgical closure by skin grafting, distant direct skin flaps (pouch or hinged flaps), pre-suturing of
346 tissue surrounding the wound, placement of devices achieves gradual closure of the wound
347 (Velcro pads, etc.). Of all these techniques, second intention healing and skin grafting are
348 amongst the commonest used. Second intention healing has the advantage of requiring less
349 surgical knowledge and may be attractive to an owner due to the lack of a surgical fee. It can be
350 very useful in contaminated or infected wounds. However secondary intention is often protracted,
351 may provide poor cosmetic results, and might result in functional disability due to scar tissue.
352 Owners often underestimate the costs of prolonged dressings. Prpich reported a 25.8% long-term
353 complication in dogs that had secondary intention healing after wide local excisions of STS in the
354 distal limb including intermittent disruption of the epidermis and decreased range of motion of
355 the carpus due to scar contracture (Prpich *et al.*, 2014). Free skin grafts have the advantage of a
356 single operation with quicker healing times, as well as potentially improved cosmetic and
357 functional outcomes. They can however be technically more challenging with associated donor
358 site morbidity. The success of the graft is mainly reliant on the establishment of a viable blood
359 supply from the wound bed; and thus graft survival is more challenging, although possible, over
360 exposed bone, joint, tendon or similarly poorly vascularized tissue. Tissue expansion offers an
361 alternative to these; it is a simple technique to perform utilising adjacent skin with an established
362 blood supply, which can therefore be used to resurface any defect regardless of the underlying
363 vascularity. Riggs et al reported the outcome of free skin grafts on 32 dogs; outcome was deemed
364 successful if $\geq 75\%$ of the original skin graft was viable 1 and 2 weeks after surgery. They
365 reported a success rate of 38% (Riggs *et al.*, 2015) but did not evaluate the associated
366 complications.

367

368 From this study it can be concluded that soft tissue expansion can be used successfully as an
369 alternative treatment for the reconstruction of limb defects in dogs where direct primary closure
370 would otherwise not be achievable. Further research into the uses of tissue expansion in
371 veterinary species is warranted, both with respect to distal limb defects, but also in alternative
372 surgical indications including potentially increasing the viability of random and axial pattern
373 flaps by pre-expansion (Cherry *et al.*, 1983) using the angiogenic properties of the “biological
374 creep” induced by STEs . The use of pre-expanded flaps would be attractive for veterinary
375 patients to potentially make them stronger to resist necrosis at their extremities, which is one very
376 common problem with these flaps (Aper *et al.*, 2003).

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Statement of conflict of interest

The devices used in the study (Self-inflating Expanding Devices) are created and manufactured by a start-up company called Oxtex

One of the co-authors is a founding director of Oxtex, with founding shares in the company. He was involved only indirectly with cases for advice on placement and case management

One other co-author is a clinical specialist at Oxtex – full time employee of the company

The corresponding author is a Veterinary advisor to Oxtex and works as an advisor for small animal cases.

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References

- APER, R. & SMEAK D. 2003. Complications and outcome after thoracodorsal axial pattern flap reconstruction of forelimb skin defects in 10 dogs, 1989-2001. *Vet Surg*, 32, 378-84
- BARTELL, T. H. & MUSTOE, T. A. 1989. Animal models of human tissue expansion. *Plast Reconstr Surg*, 83, 681-6.
- BERGE, S. J., WIESE, K. G., VON LINDERN, J. J., NIEDERHAGEN, B., APPEL, T. & REICH, R. H. 2001. Tissue expansion using osmotically active hydrogel systems for direct closure of the donor defect of the radial forearm flap. *Plast Reconstr Surg*, 108, 1-5, discussion 6-7.
- BRIGHT RM, P. C. 1985. Management superficial skin wounds. In: DH, S. (ed.) *Textbook of Small Animal Surgery*. Philadelphia: Saunders.
- CASANOVA, D., BALI, D., BARDOT, J., LEGRE, R. & MAGALON, G. 2001. Tissue expansion of the lower limb: complications in a cohort of 103 cases. *Br J Plast Surg*, 54, 310-6.
- CHERRY, G. W., AUSTAD, E., PASYK, K., MCCLATCHEY, K. & ROHRICH, R. J. 1983. Increased survival and vascularity of random-pattern skin flaps elevated in controlled, expanded skin. *Plast Reconstr Surg*, 72, 680-7.
- CHUMMUN, S., ADDISON, P. & STEWART, K. J. 2010. The osmotic tissue expander: a 5-year experience. *J Plast Reconstr Aesthet Surg*, 63, 2128-32.
- HALLOCK, G. G. 1987. Extremity tissue expansion. *Orthop Rev*, 16, 606-11.
- HUDSON, D. A. & GROB, M. 2005. Optimising results with tissue expansion: 10 simple rules for successful tissue expander insertion. *Burns*, 31, 1-4.
- KELLER, W. G., ARON, D. N., RAKICH, P. M., CROWE, D. T. & MARKS, M. A. 1994. Rapid tissue expansion for the development of rotational skin flaps in the distal portion of the hindlimb of dogs: an experimental study. *Vet Surg*, 23, 31-9.
- LANTIERI, L. A., MARTIN-GARCIA, N., WECHSLER, J., MITROFANOFF, M., RAULO, Y. & BARUCH, J. P. 1998. Vascular endothelial growth factor expression in expanded tissue: a possible mechanism of angiogenesis in tissue expansion. *Plast Reconstr Surg*, 101, 392-8.
- LOHANA, P., MOIEMEN, N. S. & WILSON, Y. T. 2012. The use of Osmed(TM) tissue expanders in paediatric burns reconstruction. *Ann Burns Fire Disasters*, 25, 38-42.
- MADISON, J. B., DONAWICK, W. J., JOHNSTON, D. E. & ORSINI, R. A. 1989. The use of skin expansion to repair cosmetic defects in animals. *Vet Surg*, 18, 15-21.
- MALATA, C. M., WILLIAMS, N. W. & SHARPE, D. T. 1995. Tissue expansion: an overview. *J Wound Care*, 4, 37-44.
- MUSTOE, T. A., PIERCE, G. F., THOMASON, A., GRAMATES, P., SPORN, M. B. & DEUEL, T. F. 1987. Accelerated healing of incisional wounds in rats induced by transforming growth factor-beta. *Science*, 237, 1333-6.
- NEUMANN, C. G. 1957. The expansion of an area of skin by progressive distention of a subcutaneous balloon; use of the method for securing skin for subtotal reconstruction of the ear. *Plast Reconstr Surg (1946)*, 19, 124-30.
- PANDYA, A. N., VADODARIA, S. & COLEMAN, D. J. 2002. Tissue expansion in the limbs: a comparative analysis of limb and non-limb sites. *Br J Plast Surg*, 55, 302-6.
- PAVLETIC, M. 2010. *Atlas of small animal wound management and reconstructive surgery*, Wiley-blackwell.

443 PRPICH, C. Y., SANTAMARIA, A. C., SIMCOCK, J. O., WONG, H. K., NIMMO, J. S. &
 444 KUNTZ, C. A. 2014. Second intention healing after wide local excision of soft tissue
 445 sarcomas in the distal aspects of the limbs in dogs: 31 cases (2005-2012). *J Am Vet Med*
 446 *Assoc*, 244, 187-94.
 447 RIGGS, J., JENNINGS, J. L., FRIEND, E. J., HALFACREE, Z., NELISSEN, P., HOLMES, M.
 448 A. & DEMETRIOU, J. L. 2015. Outcome of full-thickness skin grafts used to close skin
 449 defects involving the distal aspects of the limbs in cats and dogs: 52 cases (2005-2012). *J*
 450 *Am Vet Med Assoc*, 247, 1042-7.
 451 RONERT, M. A., HOFHEINZ, H., MANASSA, E., ASGAROUADI, H. & OLBRISCH, R. R.
 452 2004. The beginning of a new era in tissue expansion: self-filling osmotic tissue
 453 expander--four-year clinical experience. *Plast Reconstr Surg*, 114, 1025-31.
 454 RYAN, S., WOUTERS, E. G. H., VAN NIMWEGEN, S. & KIRPENSTEIJN, J. 2012. Skin and
 455 subcutaneous tumors. In: WILEY & SONS, L. (ed.) *Veterinary Surgical Oncology*.
 456 SHARPE DT, C. D. 1992. Further developments in tissue expansion In: JACKSON IT, S. B.
 457 (ed.) *Recent Advances in Plastic Surgery* 4th ed. Edinburgh: Churchill Livingstone
 458 SPODNICK, G. J., PAVLETIC, M. M., CLARK, G. N., SCHELLING, S. H. & KRAUS, K. H.
 459 1993. Controlled tissue expansion in the distal extremities of dogs. *Vet Surg*, 22, 436-43.
 460 SWAIM, S. 1980. *Surgery of Traumatized Skin: Management and Reconstruction in the Dog and*
 461 *Cat*, W.B. Saunders Company.
 462 SWAN, M. 2007. *Anisotropic Self-inflating Tissue Expanders in Reconstructive Plastic Surgery*
 463 Doctor of Philosophy, The University of Oxford
 464 SWAN, M. C., BUCKNALL, D. G., CZERNUSZKA, J. T., PIGOTT, D. W. & GOODACRE, T.
 465 E. 2012. Development of a novel anisotropic self-inflating tissue expander: in vivo
 466 submucoperiosteal performance in the porcine hard palate. *Plast Reconstr Surg*, 129, 79-
 467 88.
 468 SWAN, M. C., BUCKNALL, D. G., GOODACRE, T. E. & CZERNUSZKA, J. T. 2011.
 469 Synthesis and properties of a novel anisotropic self-inflating hydrogel tissue expander.
 470 *Acta Biomater*, 7, 1126-32.
 471 TAYLOR, G. I., CORLETT, R. J., CADDY, C. M. & ZELT, R. G. 1992. An anatomic review of
 472 the delay phenomenon: II. Clinical applications. *Plast Reconstr Surg*, 89, 408-16;
 473 discussion 417-8.
 474 VAN RAPPARD, J. H., SONNEVELD, G. J. & BORGHOUTS, J. M. 1988. Geometric planning
 475 and the shape of the expander. *Facial Plast Surg*, 5, 287-90.
 476 WILHELMI, B. J., BLACKWELL, S. J., MANCOLL, J. S. & PHILLIPS, L. G. 1998. Creep vs.
 477 stretch: a review of the viscoelastic properties of skin. *Ann Plast Surg*, 41, 215-9.
 478

Figure legends

Figure 1: Oxtex 27mm self-inflating tissue expander. Left : before expansion ; right: after expansion

Figure 2a. Image of the metatarsal area of a dog presented for a lick granuloma (blue circle). The yellow dotted line represents the proposed incision to place the expanders (2 full circles). The two purple lines are the proposed incisions at the end of the expansion period. The purple line indicates the incision needed to create an advancement flap from the expanded skin. Alternatively a rotation flap (red line with two green arrows) could be undertaken

Figure 2b. Placement of two expanders within a subcutaneous pocket, as per planned diagram in Figure 2a

Figure 3: Step by step procedure from implantation to explanation of the STEs

a: Incision along lateral margin, b: Implantation of 2 STEs, c: STE's *in situ* post implantation, d: 14 days post implantation, e: Explantation of STEs, f: Removal of STS and lateral margins, g: Advancement flap created, h: Sutures removed 14 days post reconstruction. STE = Self-inflating Tissue Expanders

Table 1: Case description and reason for skin expansion

Case number:	Group	Age (years)	No. of devices implanted	Reason for reconstruction	Size of defect to be reconstructed
1	C	7	2	MCT	3.0 x 3.5 cm
2	B	7	2	STS	2.5cm diameter
3	C	7	2	NNM	3.0 x 3.5 cm
4	A	13	2	NHW	4.0 cm diameter
5	B	7	6	NHW	10.0 x 8.0 cm
6	B	7	6	NHW	Not recorded
7	B	Not recorded	8	STS	6.0 x 5.0 cm
8	A	6	9	NNM	6.5 x 6.0 cm
9	A	5	6	STS	2.5 x 4.0 cm
10	A	8	6	NHW	3.5 x 3.5 cm
11	C	Not known	2	STS	3.0 x 2.5cm
<u>12</u>	<u>C</u>	<u>13</u>	<u>2</u>	Benign sebaceous adenoma <u>NNM</u>	<u>2.0cm diameter</u>

MCT (mast cell tumour), STS (soft tissue sarcoma), NNM (Non neoplastic mass), NHW (non healing wound), TN (tissue necrosis)

Table 2: Complications and Outcomes following skin expansion

Dog case Number:	Complications during expansion Reasons Major/Minor	Primary closure achieved	Complications post reconstruction (Y/N)	Procedure grading	Owner outcome
1	Major – Tissue necrosis	N	N – Healed via 2 nd intention	Fair	Not Satisfied
2	None	Y	N	Excellent	Satisfied
3	Major – Tissue Necrosis	N	N – Healed via second intention	Fair	Satisfied
4	None	Y	Y – 50% ischemic flap – Healed via second intention	Fair	Satisfied
5	Minor - infection of wound	Y	N	Good	Satisfied
6	None	Y	Y – 0.4cm tip of advancement flap ischemia – Healed via second intention	Good	Satisfied
7	Minor – incisional infection	N	N – partial closure healed via second intention	Good	Not Satisfied
8	None	Y	N	Excellent	Satisfied
9	None	Y	Y – Wound dehiscence– Healed via secondary intention	Fair	Satisfied
10	None	Y	Y – Wound dehiscence healed via secondary intention	Fair	Not Satisfied
11	Minor – Tissue Necrosis	Y	N	Good	Satisfied
12	Major- vascular compromise	N/A	N/A	Poor	N/A

